

## **Cheap DECAF: Density Estimation for Cetaceans from Acoustic Fixed Sensors Using Separate, Non-Linked Devices**

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### **LONG-TERM GOALS**

Several of the current methods for density estimation of cetaceans using passive fixed acoustics rely on large, dense arrays of cabled hydrophones and/or auxiliary information from animal tagging projects conducted at the same time as the acoustic survey. Obtaining such data is costly, and may be impractical to the wider community interested in estimating cetacean density. Therefore, the goal of Cheap DECAF is to focus on the development of cetacean density estimation methods using sensors that are sparsely distributed and less expensive to deploy than the cabled military arrays focussed on to date.

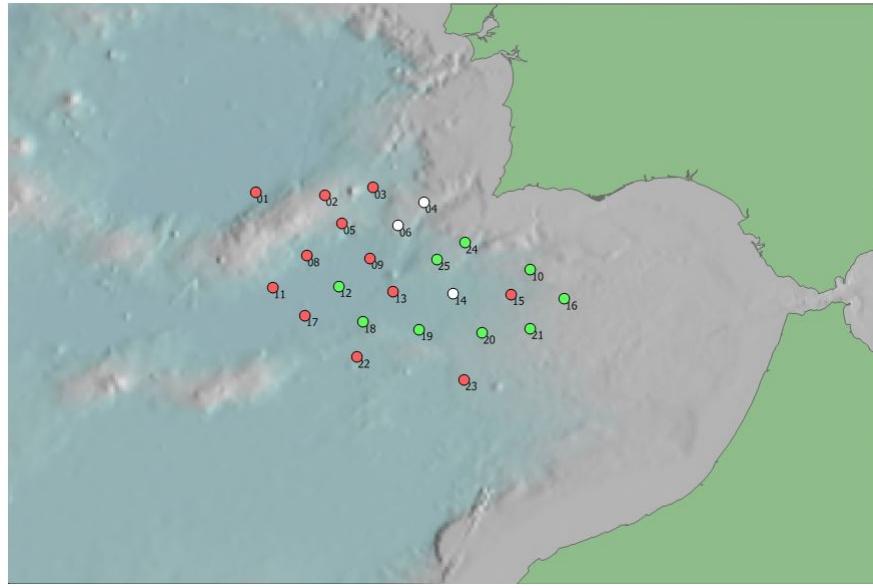
### **OBJECTIVES**

Recordings of fin whales (*Balaenoptera physalus*) from a sparse array of Ocean Bottom Seismometers (OBSs) are being used to develop and test a variety of density estimation methods. The OBS array was deployed for 1 year (2007-2008) off the south coast of Portugal, near the Straits of Gibraltar (Fig. 1).

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The specific objectives of the project are to

1. demonstrate how cue-counting methods can be used efficiently to obtain estimates of density over long time periods and large spatial scales using directional sound sensors;
2. extend the methods to allow for uncertainty in the depth of vocalising animals;
3. develop and apply methods based on tracking moving individual animals;
4. develop and apply methods based on measuring total sound energy in relevant frequency bands;
5. obtain baseline estimates of spatial density of fin whales in the study area.



**Fig. 1. Location of the array of 24 OBS sensors in the Atlantic off Portugal. Green denotes instruments that could range to detections for their entire deployment, red denotes instruments that could not range to detections and white denotes instruments that could range to detections for parts of their deployment.**

## APPROACH

This project is in collaboration with the University of St. Andrews (grant number: N00014-11-1-0615, PI: Len Thomas). The work is divided into 3 components, as follows:

Component 1: Fin whale vocalisations have been automatically detected and localised across the 1-year dataset, using existing methods. Established distance sampling methods using cue counting have been used to generate seasonal call density estimates, and spatial patterns in call density have been related to oceanographic features (an appropriate calling rate is required in order to generate estimates of animal density from call densities). Customised distance sampling software has been used (Thomas *et al.*, 2010). This component has also included the development of methods to account for the depth distribution of animals, which involved a simulation exercise.

Component 2: This component will focus on estimating density where the unit of interest is the individual animal, rather than a cue, i.e., vocalisations. Methods to account for the movement of individual animals are being developed via a simulation study, building on work completed for a Master's thesis (DiTraglia, 2007).

Component 3: This component is developing a method that uses the total energy present in a species' frequency band as the statistic upon which a density estimate is made. The approach used involves a Monte Carlo simulation and propagation modelling, to link density of animals to a given received energy level.

Components 1 and 2 are being led by the University of St. Andrews, and Component 3 is this project. There is also a project management element, coordinating bi-monthly tele-conference progress meetings, and at least two face-to-face meetings, one in each project year.

## WORK COMPLETED

We have continued to have tele-conference meetings (at least bi-monthly). In addition, we have had two face-to-face project meetings: one in Lisbon in mid-October 2012 and another in St Andrews in June 2013. We have also had a paper accepted (Harris *et al.*, in press). This paper provides an overview of the signal localisation method using single OBSs, reports the results of a validation study using airgun shots of known location (completed in the previous FY) and demonstrates the application of distance sampling to OBS data. Presentations about Cheap DECAF have also been given at the 6th International Workshop on Detection, Classification, Localization, and Density Estimation (DCLDE) of Marine Mammals using Passive Acoustics held in St Andrews, UK, in June 2013, at the UK National Centre for Statistical Ecology summer meeting held in Lowestoft, UK, in July 2013, and at the spring 2013 meeting of the Acoustical Society of America, held in Montreal (associated conference paper: Mellinger 2013). In addition, a poster presentation was given at the European Cetacean Society conference held in Setúbal, Portugal, in April 2013.

Under Component 1, the detection and localisation routine has been refined based on results from the airgun validation. The entire year of data has been reprocessed to incorporate these refinements. Further development of the localisation method and another validation analysis using tracks of fin whale calls (which have been tracked using traditional time difference of arrival methods using multiple OBSs) has also been completed by Matias. The analysis of the detected fin whale calls across the array has been expanded to a three-stage analysis. Firstly, multiple covariate distance sampling has been used to analyse the available range data (not all OBSs could produce estimates of range to detections (Fig. 1)). Multiple covariate distance sampling incorporates relevant variables into the detection function model, which may improve the model fit (Marques *et al.*, 2007). The resulting detection function has been used to estimate call density around each OBS (thereby incorporating data from the non-ranging OBSs). Secondly, a generalised additive model (GAM) that incorporated environmental covariates has been used to explore the spatial and temporal patterns of call density (Wood, 2006). Finally, using the results from the GAM, a call density surface has been fitted across the study area, predicting the spatial and temporal patterns of fin whale calling in this region. Variance of the density surface has been estimated using bootstrapping techniques. This work forms the basis of two manuscripts being prepared. One manuscript will describe the localisation method in more detail and include the method validation using fin whale tracks. The other manuscript will report the results of the three-stage analysis described above.

The effect of animal depth on distance sampling analyses has also been explored. The distance sampling methodology has been adjusted to include auxiliary data about the distribution of animals in relation to depth and has been tested via simulation. A stand-alone manuscript detailing this method development is being prepared.

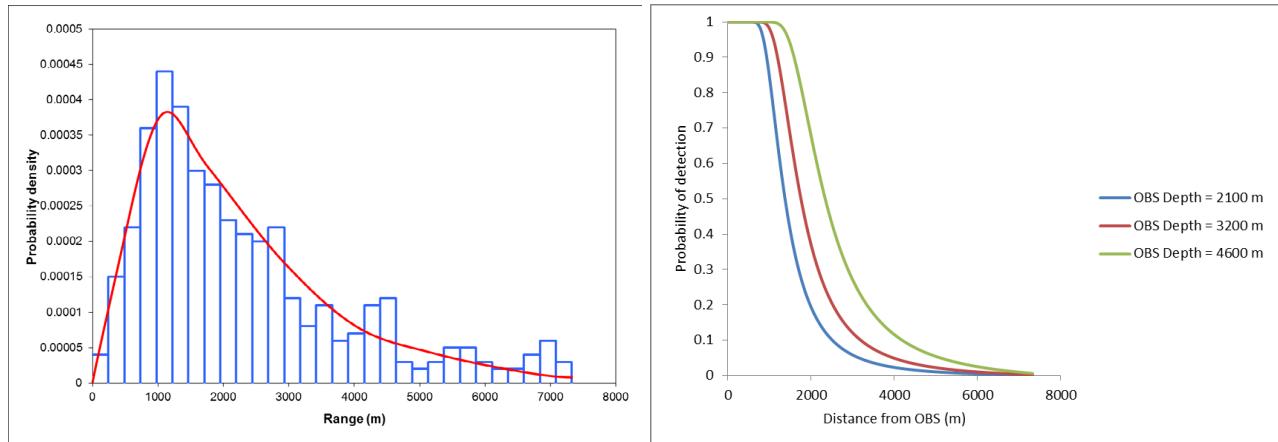
Under Component 2, work has begun to extract and fit movement models to the fin whale tracks generated in Component 1.

Under Component 3, noise-reduction methods were applied to make optimal estimates of the energy present over the year in the fin whale frequency band. Noise elimination methods, which are based on successive linearly-scaled power spectra (a “power spectrogram”), focused on two types of noise reduction: (1) harmonic noise such as that from ships, which is lessened by finding spikes in the power spectrum, removing them, and interpolating across the removed frequencies; and (2) broadband noise, whether impulsive or relatively stationary, which is lessened by estimating its level at frequencies below and above the target frequency band and interpolating between them to estimate what portion of the measured energy is from noise and what from fin whales.

The other major computational task is to run acoustic propagation models to estimate the propagation loss from points in and near the hydrophone array to each hydrophone.

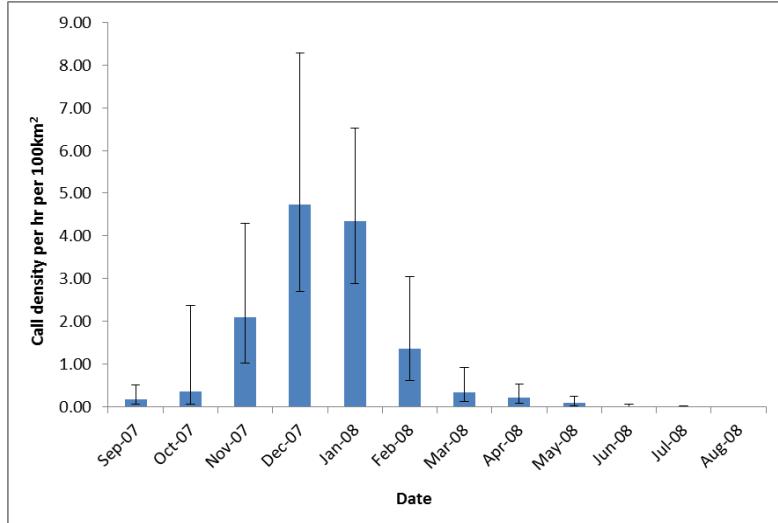
## RESULTS

Using the updated detection and localisation criteria, 14,058 presumed fin whale calls with associated ranges were detected between September 2007 and August 2008. The best fitting detection function model to these data was a hazard rate model with an extra simple polynomial adjustment parameter and OBS depth and month as covariates (Figs 2 & 3). Ambient noise was also trialled as a covariate but produced counterintuitive results (i.e., a greater detection probability was predicted for higher ambient noise levels), which requires further investigation.



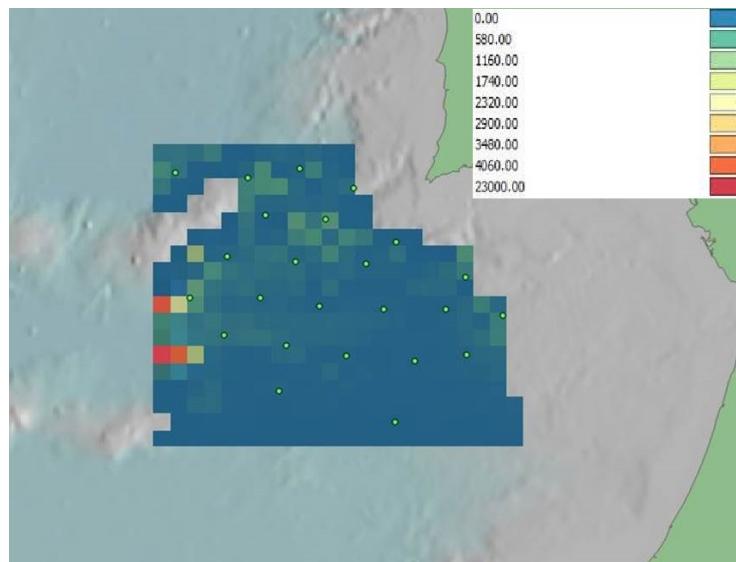
**Fig. 2 (left)** Distances (grouped, histogram) and estimated probability density function for observed distances (red line). **Fig. 3 (right)** Detection function for January 2008, at three different OBS depths.

Average call density for each month ranged between 0 and 4.7 calls per hour per  $100 \text{ km}^2$ . The minimum and maximum monthly call densities were in August 2008 and December 2007, respectively (Fig. 4). The overall pattern of call density is very similar to the preliminary results presented in the FY2012 report, although the densities are an order of magnitude smaller – this highlights the importance of the need to fully understand the detection and localisation processes.



**Fig. 4 Preliminary monthly call densities with 95% confidence intervals displayed. Units are calls/100 km<sup>2</sup>. hr<sup>-1</sup>.**

The spatiotemporal modelling results suggested that time of year, depth, seafloor slope, shipping levels, ocean surface velocity, sea surface temperature, latitude and longitude were all significant explanatory variables of the spatiotemporal patterns of fin whale calling activity (fitted using a GAM with a quasipoisson error distribution). This model was used to predict density surfaces across time e.g., Fig. 5 shows the density surface model predicted for 31 October – 4 November 2007. Edge effects (unexpectedly high or low predicted values) are apparent in some of the fitted surfaces (e.g., Fig. 5). These can be caused by extrapolation of the spatiotemporal model at the prediction stage. Efforts to reduce edge effects were made by restricting the prediction grid, but further refinement is required.



**Fig. 5 Predicted fin whale call counts between 31 Oct – 4 Nov 2007 in 14 km<sup>2</sup> grid cells across the wider study area. The grid is irregular due to shallow bathymetry – predictions were not made where ocean depth <2000 m as this would have been extreme extrapolation of the model. The green circles indicate the OBS locations.**

The main results from the method development work to account for animal depth are that the simulations are returning unbiased, or minimally biased, estimates of animal density under several monitoring scenarios. The methods can be applied to towed or stationary acoustic surveys, and can also be applied when only bearing (rather than range) to the calling animal has been measured.

Using the noise reduction methods described above, fin whale call energy was estimated for the entire dataset to arrive at noise estimates for the one-year span of the dataset each of the 24 hydrophone locations. Acoustic propagation modeling was also performed to estimate propagation loss on 8 radials surrounding each hydrophone. These results, combined with a distribution of call periods having a mode of 18 s for this population of fin whales (Hatch and Clark, 2004), are now being used to estimate the fin whale population density at each site throughout the year.

## IMPACT/APPLICATIONS

The main aim of Cheap DECAF is to make density estimation of cetaceans less costly and, therefore, more accessible to the wider scientific community. The methods developed here will be applicable to re-deployable arrays of both sea-bed mounted instruments (such as the OBS array) and surface buoys, so should increase our capability to monitor cetacean density in geographic areas of interest, including those where naval operations are conducted.

## RELATED PROJECTS

Cheap DECAF (Grant number: N00014-11-1-0615, PI: Len Thomas, University of St. Andrews)

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